

DEVELOPMENT OF ROAD SURFACE CONDITION SENSOR USING BY OPTICAL TEMPERATURE SENSOR AND WEATHER SENSOR

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SUMMARY

Advanced Cruise-Assist Highway Systems (AHS) aim to improve road traffic safety and transport efficiency, and to achieve this it is necessary to develop technologies capable of accurately understanding safe cruising speeds and vehicle headway. These phenomena are closely related to road surface conditions, and the authors have thus far investigated road condition sensors that can be applied to AHS. ¹⁾ One of these is an optical fiber type road condition sensor that simultaneously detects the temperature distribution along an optical fiber imbedded in the road and the road condition distribution along the road using weather data measured by weather sensors. This paper presents an outline of this sensor and reports the development progress thus far centering on the results of field tests on actual roads in cold districts.

OUTLINE OF ROAD CONDITION SENSOR

System Configuration

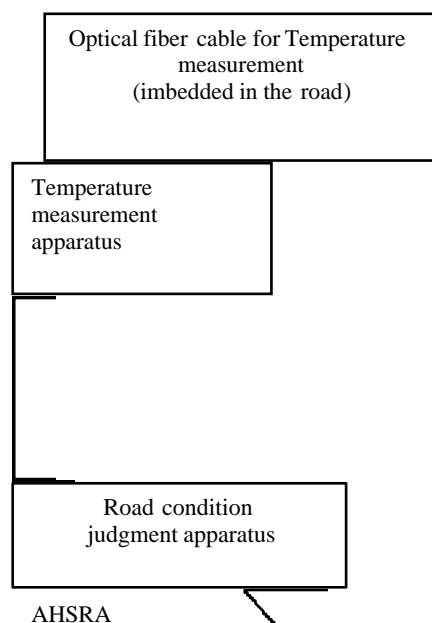
Fig. 1 shows the system configuration and the specifications of the component equipment. This system is comprised of an optical fiber imbedded in the road and a temperature distribution measurement apparatus to measure the longitudinal temperature distribution, meteorological gauges (thermometer, hygrometer, rain and snow gauges, anemometer, and pyrliometer) installed near the road, and a judgment apparatus which classifies road conditions into five categories based on the various measurement data.

The temperature distribution measurement apparatus emits a high-output light pulse into the optical fiber, and measures the temperature from the strength of the Raman scattering light generated inside the optical fiber, and the location from the time difference from when the Raman scattering light is generated until it returns to the emission point. The road surface temperature distribution in the longitudinal direction is obtained by imbedding an optical fiber cable for temperature measurement at a depth of 30 mm below the road surface. This temperature measurement optical fiber is covered by a stainless steel tube to improve mechanical strength and thermal responsiveness.

The meteorological gauges have the same functions as general meteorological observation

equipment. The instruments needed to understand the heat balance to the road surface were used.

The road condition judgment apparatus judged the road condition according to the algorithm described in next section based on the road surface temperature distribution and weather data mentioned above. Note that dial-up functions were added to the external interface functions for this study to allow output results to be obtained as desired via telephone lines from AHSRA.



Equipment		Specifications
Temperature measurement apparatus		Temperature accuracy : $\pm 1^{\circ}\text{C}$ or less Measurement distance : 15kmMAX Distance resolution: 1m Measurement time : 1min CPU : Pentium500MHz Memory 32MB I/F : 10base-T
Optical fiber cable		50/125GI SUS tube sheath($\phi 4\text{mm}$)
Meteorological gauges	Thermometer	Range : -20°C \sim 40°C Accuracy : $\pm 1^{\circ}\text{C}$ or less
	Hygrometer	Range : 0% \sim 100% Accuracy : $\pm 5\%$ or less
	Rain and snow gauges	Rainfall : 0.2mm or less
	Anemometer	Range : 0 \sim 70m/s Accuracy : 0.5m/s
	Pyrheliometer	Sensitivity : 10mV/kW m^2
Road condition judgment apparatus		Output : 5 conditions(dry, wet, water film, snow-covered, icy) in 5m units in the longitudinal of the road, time characteristics display function Output cycle : 1 minute CPU : Pentium500MHz Memory : 32MB I/F : 10base-T Dial-up functions

Figure 1 System Configuration and Equipment Specifications

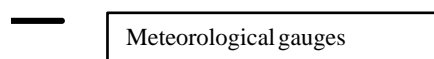
Road Condition Judgment Algorithm

Fig. 2 shows an outline of the algorithm used to judge road conditions. This sensor judges the road condition using the thermal characteristics produced by the presence or lack of deposits on the road surface. Concretely, when a certain amount of heat is applied to the road surface in the dry and wet conditions, the road surface temperature rise value for the wet condition is smaller than the temperature rise value for the dry condition because a part of the heat is taken as latent heat in order to evaporate the moisture on the surface. In other words, the road condition can be judged by comparing the hypothetical road surface temperature rise value for the dry condition with the actual road surface temperature rise value. (Here, the ratio $\Delta T_e / \Delta T_t$ is indicated as the temperature change ratio.) The actual road surface temperature is obtained as the change in temperature per unit time which is in turn obtained from the road surface temperature values measured by the optical fiber temperature distribution sensor. On the other hand, the hypothetical road surface temperature rise value for the dry condition, which is required for this operation, is obtained by inputting the measurement values from the meteorological gauges and solving the equation for the calculated thermal conductivity from underground to the ground surface. Next, the dry, wet, snow-covered and frozen conditions are judged by plotting on the judgment chart using the judgment criteria given below based on the relationship between the temperature change ratio obtained by the above method and the actual road surface temperature. Further, the reliability of the road condition output was improved by using time series data of the judgment results. Note that the water film condition was detected using the amount of rainfall, angle of road surface inclination, and road surface irregularity, etc.

Figure 2 Road Condition Judgment Algorithm

OUTLINE OF FIELD TESTS ON ACTUAL ROADS

These sensors were installed near Nakayama Pass on general road 230 and near the Ibuki Parking Area on the Meishin Expressway to evaluate the judgment performance for various road conditions in cold districts. Fig. 3 shows an outline of test conditions near Nakayama Pass on general road 230. The system was installed in a mountainous region with a slight incline and sloped surfaces on both the left and right sides of the road, so sunny and shady spots easily formed at the same time. The optical fiber for temperature measurement was approximately 450 m long to detect changes in the road condition in the longitudinal direction.



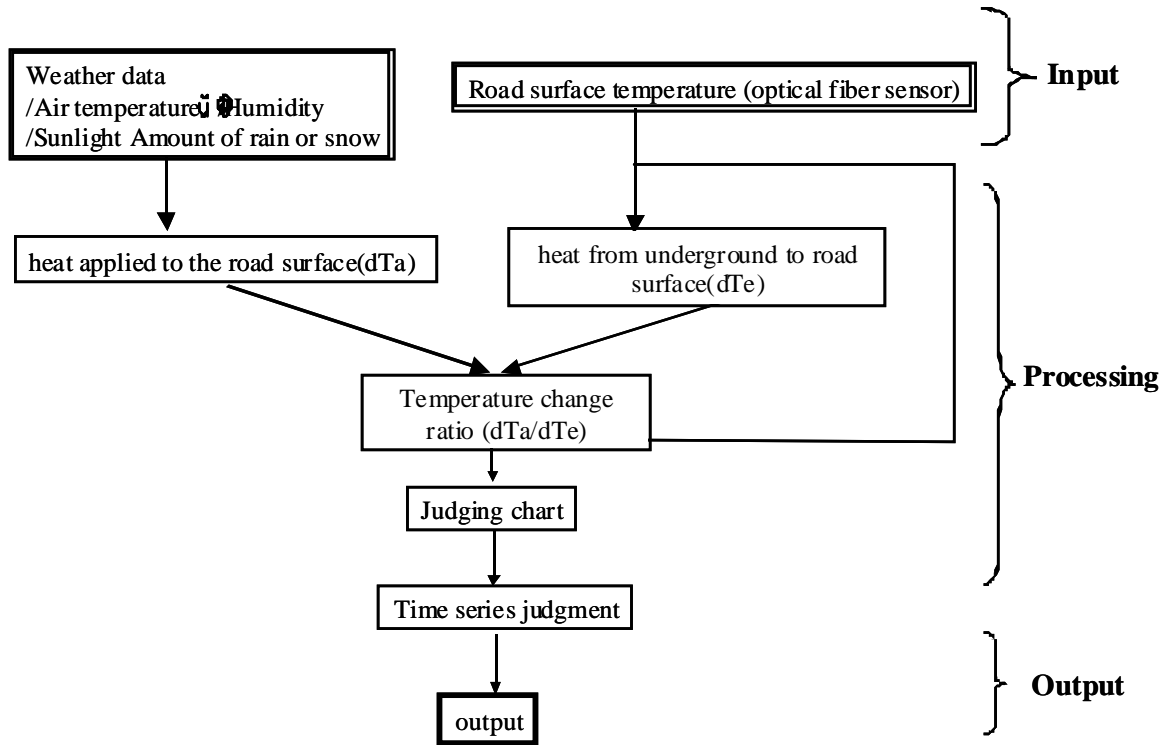


Figure 3 Test outline

In addition, the road condition data needed to evaluate the road surface judgment performance of the sensor was acquired through visual observation of the road surface by on-site observers (every ten minutes) and from images filmed by separately installed reference cameras. Note that the road condition judgment standards used by observers when directly evaluating road conditions by visual observation and when evaluating conditions through the reference cameras were referenced from materials published by public organizations.²⁾

TEST RESULTS

Fig. 4 shows an example of the test results. Fig. 4(a) shows the road condition output and corresponding weather condition time characteristics at a specified our road condition sensor point. In this example, the road surface was the wet condition due to moisture-laden snowfall during the day. After that, the air temperature dropped suddenly and further snowfall resulted in the snow-covered condition. This figure also shows the road condition obtained through visual observation, and the sensor output and visual results match closely. The sensor output was approximately 10 minutes early in indicating the start of the snow-covered condition, but this is a judgment to the safe side, so it is not thought to pose a problem for actual use.

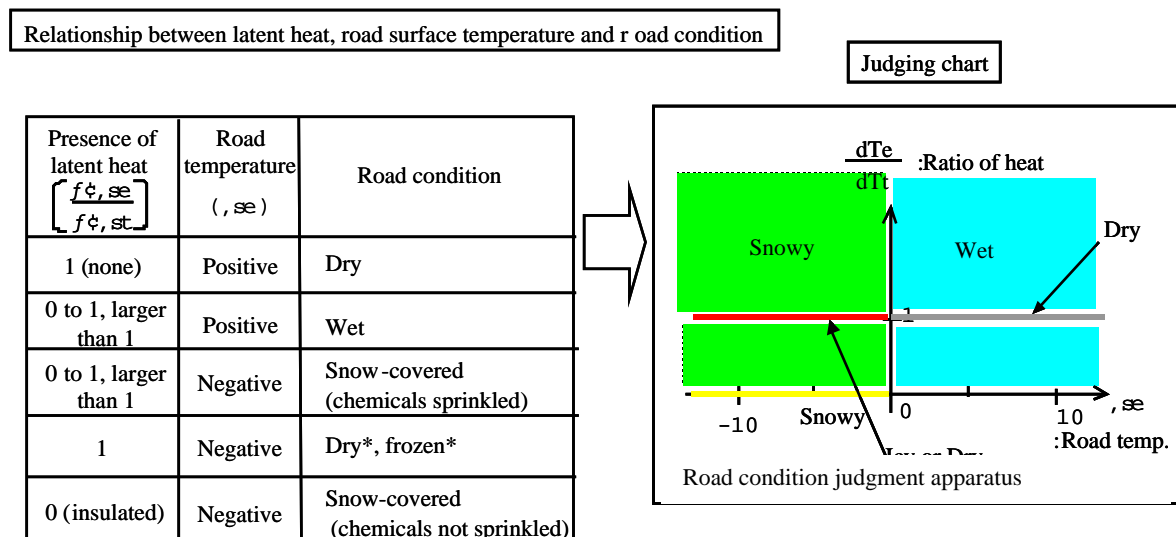
Fig. 4(b) shows an example of the frozen road condition with the ice gradually melting and changing to the wet condition as the sun rises. The amount of sunlight increased greatly from around 10:00 a.m., and the wet condition resulted approximately 40 minutes after that. The visual observation results also match relatively closely. The sensor output was approximately 20 minutes late in indicating the start of the wet condition, but this is a judgment to the safe side, so it is not thought to pose a problem for actual use.

Fig. 4(c) shows the road condition distribution output in the longitudinal direction for example (b). The number of visual observation points increased to three locations, but the output matches closely with the actual road conditions, thus confirming that this sensor can

correctly judge road conditions on an actual road.

The road condition judgment rate was calculated from the above results to objectively evaluate the sensor performance. These results are given in Fig. 4(d), and show that the detection rate for the optical fiber road condition sensor was 80.5%. This indicates that steps must be taken such as optimizing various parameters or combining other sensors in order to increase the detection rate.

Thus, the road condition distribution output in the longitudinal direction can be considered useful as adverse road surface information in all service sections required by AHS, and also effective for advancing the level of road management operations such as calculating the minimum necessary amount of anti-freezing agent to be sprinkled.



Test conditions

Fig.4(c) Test Results(3)



図 4-6



図 4-7

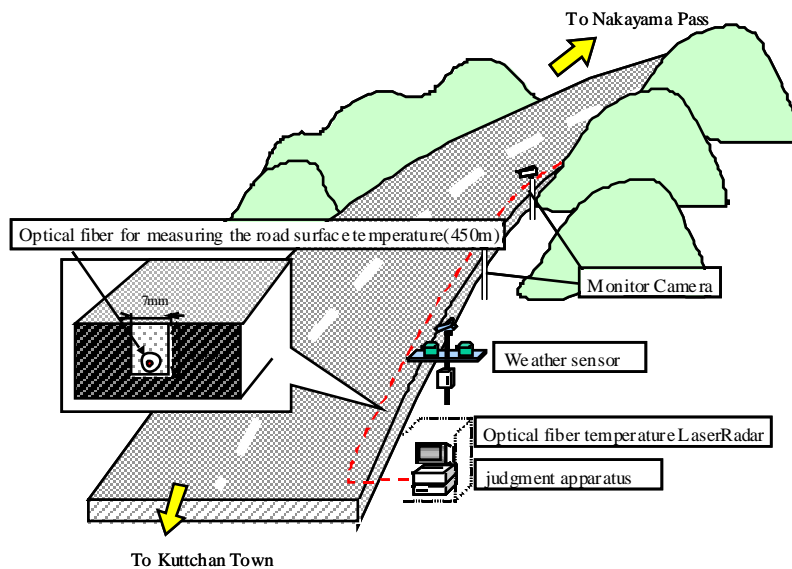


Figure 4 Test Results

CONCLUSION

This paper presented the development progress of a road condition sensor which is essential for AHS. In the future we intend to continue evaluation and improvement of sensor performance on actual roads, and to work toward practical application through investigations including the effects of application to various AHS services and road management.

This study was commissioned by the National Institute for Land and Infrastructure Management of the Ministry of Land Infrastructure and Transport.

REFERENCES

- 1) Y. Miyata, et al, "Development of Road Condition Sensing Systems", Proceeding of the 5th World Congress on ITS.
- 2) Ishihara, Onoda, "Road Surface Freezing and Countermeasures", Gijutsushoin, etc.